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Development of a new positioning system for underwater robot based on sensor network

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Abstract: We are developing a new positioning system for underwater vehicle based on sound power decreasing with transmitted distance and sensor network technology. Conventional positioning system is using the difference between sounded time at station and received time on vehicle. However it is so much expensive, requires high operational cost and measuring field is not so wide. Then we need some new positioning system of low cost, easy operation, easy maintenance and high accuracy. Our system is expected to satisfy such kinds of requirements. At the first stage, we confirmed the principal with theoretical and experimental method. In the research, we treated only the directly arrived wave in the received data. It showed a good precision for short range of distance but also showed that it was easily affected by the reflected wave, and positioning area was limited with in only several hundred meters when the reflective surface existed near to receiver. Those were reported in AROB2008. Therefore, we tried a new idea that is using a low frequency sound and sending plural frequency sounds simultaneously, as the second stage of this study. We are trying to confirm the performance of the method. This paper showed the results of the simulation and the water tank experiment. With these improvements, the influence of reflection was suppressed and positioning area became larger than former research. Then the under water positioning system using sound power transmission loss will come to useful.

Keywords: Underwater positioning, Sensor network, Propagation loss

I. INTRODUCTION

Depending on the needs for natural resources inquiry, environmental protection and prediction of earthquake, the role of underwater vehicle becomes more and more important. In particular, the functional improvements for Autonomous Underwater Vehicle (AUV) which can achieve a given mission automatically without support of operator or mother ship in deep sea, is becoming an urgent matter. Recently, AUV-Urashima of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has succeeded in the autonomous underwater navigation of 317km. [1] However, it proved that the conventional positioning system was not convenient and cannot perform the ability of AUV's autonomy completely. For this reason, a new type of underwater positioning system which is covering wide area, easy operation, easy maintenance, high accuracy and not so expensive is thought to be necessary for AUV's effective work.

Depending on these needs, we started to develop a new positioning system for underwater vehicle based on sound power decreasing with transmitted distance and sensor network technology. It is using monotone sound, so the system configuration becomes very simple, and system cost is lower than conventional system, which is using time difference between station and vehicle measured with high accurate clock. And sensor network can cover wide area. Then our system is expected to satisfy such kinds of requirements.

At the first stage, we confirmed the principal with theoretical and experimental method. In the research, we treated only the directly arrived wave in the received data. It showed a good accuracy for short range of distance but also showed that it was easily affected by the reflected wave, and measuring distance was not so long when the reflective surface was near. Those were reported in AROB2008[2][3]. Therefore, we tried a new idea that is using a low frequency and sending plural frequency sounds simultaneously, as the second stage of this study. We are trying to confirm the performance of the method. This paper showed the results of the simulation and the water tank experiments.

II. PRINCIPLE OF MEASUREMENT

We define sound power decreasing as that the amplitude of sound becomes small depending on a distance when a sound is propagating in a medium.

Sound power decreasing is composed of a diffusion decreasing, an absorption decreasing and a reflection decreasing. When the distance to reflective surfaces is far, we can get typical signal like Fig.1 (a). In this case, direct wave and reflected wave are divided clearly, then r[m] (Propagation can be calculated with PL[dB] (Propagation Loss) easily.[2][3] But when reflective surface is near or the propagation distance is far, the reflected wave is so near to direct wave and they become hard to separate as Fig.1 (b). fr[kHz] is Sound frequency.

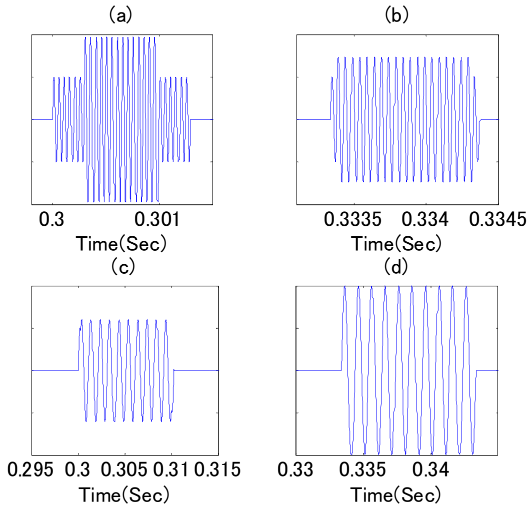

Fig.1. Examples of simulation
(a) fr=20kHz, r=450m; (b) fr=20kHz, r=3500m
(c) fr=1kHz, r=450m; (b) fr=1kHz, r=3500m

We could suppose that a sound wave produces specular reflection when it comes across flat-water surface, like Fig.2. [4] Evidently accompanied with the distance between sender and receiver, the difference of arrival time between direct wave and reflected wave becomes short.

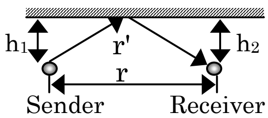

Fig.2. Reflection model
h_1: Depths of sender; h_2: Depths of receiver;
r: Propagation distance of the direct wave;
r': Propagation distance of the reflected wave;

In this case, if send a sound wave of lower frequency, we can find direct wave and reflected wave are nearly piled up with same phase as Fig.1 (d). The total energy of received wave can be calculated with the sums of energy of both waves. And the energy of reflected wave is proportional to the direct wave. So we suppose that the received power becomes k times of PL of the direct wave and error A, as Eq. (1). Here, k is influenced by reflectance, and it is measured on the site.

$$PL = k(20\log10(r)+\alpha r)+A \qquad (1)$$

However, this equation is only effective when the phase difference of both waves is smaller than $\pi/4$, and the error is affected with the phase difference. For example, when send sound waves of 1 kHz similarly, the phase difference of r=3500[m] is smaller than r=450[m] as Fig.1(c), (d). So the error by the phase difference shrinking. On the other hand, PL can also be calculated as Eq. (2).

$$PL = 20\log10(Te) + Tx+Rx+Rg-20\log10(Re) \qquad (2)$$

Here, Te is a power of send signal and Re is of received signal, and calculated with FFT. Transmission sensitivity Tx [dB], receiving sensitivity Rx [dB] and reception gain Rg [dB] are constants.

III. DATA PROCESSING

This section is explains the calculation process for distance r from recorded wave signal. At first, we measure the receiver's depth and height with depth sensor and altimeter. Then we estimate the phase difference between direct wave and reflected wave, and choose the handling method of signal. When it fills the mode of direct wave, it can be handled as references [2] [3]. Or else, it can be handled as Fig.3. We firstly use band pass filter to reduce the influence of noise and find the initial point of the received signal. Then separate necessary data from received data and calculate signal power Re [dB] with FFT, so Propagation Loss PL [dB] can be calculated. In other hand we calculate error A with using h_1,h_2, and calculate true value of propagation distance r[m] with using Eq. (1) and Eq. (2).

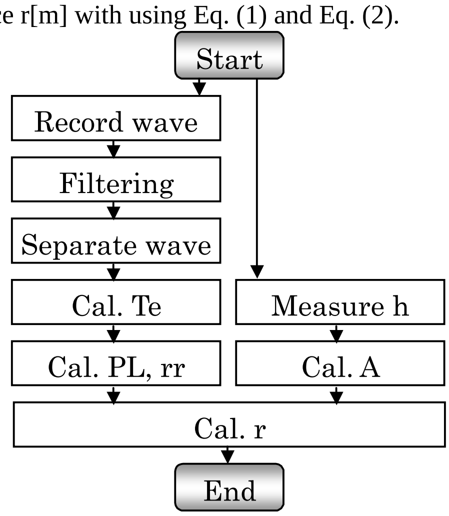

Fig.3. Signal processing flow

Fig.4 shows an example of data processing. Fig.4 (a) is a measured data. It shows the signal is sounded every 0.5sec, including more reflected waves and hard to distinguish the direct wave. After filtering, we get clear wave (Fig.4-(b)). Fig.4-(c) is pick-upped wave from (b) with separation and (d) is the result of FFT. In the sea area, as the most remarkable reflection is from surface or sea floor, we can suppose that the wave of only one time reflection is countable.

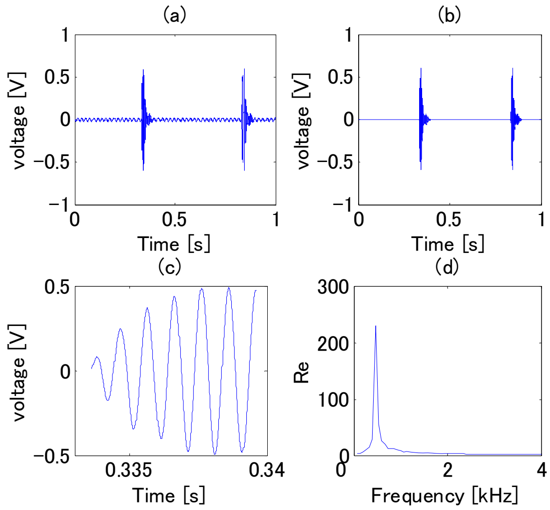

Fig.4. Example of received data

IV. WATER TANK EXPERIMENTS

1. EXPERIMENTAL CONTENTS

To confirm the practical performance for this new idea, we accomplished the experiments with using ultrasonic signal transmission and reception system in the water tank of JAMSTEC.

Fig.5 is the tank used for this experiment.

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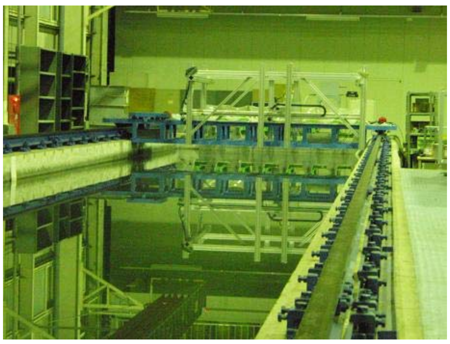

Fig.5. Water tank

In this study we used a lower frequency sound of fr = 1[kHz], and omni-directional transducer, and set it at middle position of the depth and center position of tank width as shown in Fig.6. Then the reflected waves from surface and bottom arrived at transducer in the same time approximately. The reflection waves from right and left sidewall are also same condition.

Fig.6. Transducer (sender)

Fig.7 shows the outline of the experimental system. It is consisted of a function generator, a power amp, a transducer (sender), a transducer (receiver), a pre-amplifier, an AD converter and a PC. In this experiment, we used software band-pass filter instead of hardware.

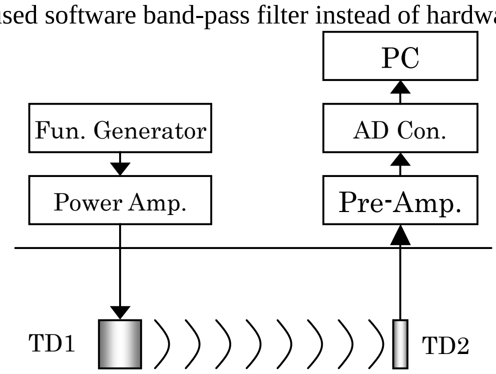

Fig.7. Configuration of experimental system

Then we set the sampling frequency of received wave in 200 kHz, measured the true distance with ruler, and record the data with changing distance from 3 meter to 25meter with every 1 meter. Table.1 shows the condition of this experiment.

Table 1. Condition of water tank experiment

Sound frequency	1[kHz]
Size of water tank	40[m](L)×4[m](W) ×2[m](D)
Size of transducer	Sender: 16.6[in.](D)×12.9[in.](H) Receiver: 3[in.](D)×10[in](H)
Signal pattern	10[Waves/10msec], 2Times/sec
Distance	3-25[m], pitched with 1[m]

2. EXPERIMENTAL CONFIRMATION

In this section we'll show the results of simulation and water-tank experiment without error compensation. At first, we show the result of Simulation in Fig. 8. In the simulation we supposed that tank size is same as experimental tank, and sound come out from point source and receiver is also point. In Fig. 8, the horizontal axis is propagation distance and vertical axis is power loss.

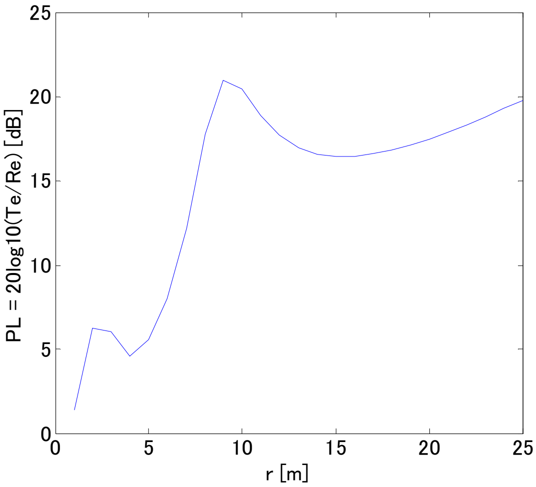

Fig.8. Simulation result of r

Fig.9 shows the experimental results of PL. It is calculated with received wave of water-tank experiment data. We can say that this result has a rough similarity to the result of simulation in shape. But there is some disturbance on the waves caused of second reflections or third reflections.

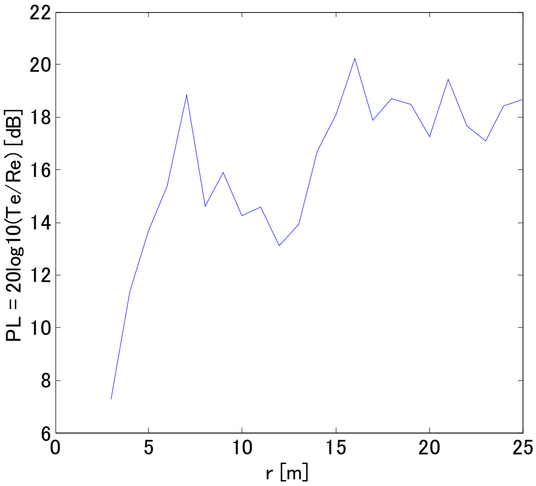

Fig.9. Result of water-tank experiment

Fig.10 shows the error compensation of the water-tank experiment. Errors became small with k. As Fig.10, area A is available of positioning with direct wave, area B has an influence of phase difference and area C is using the suggested method in this study. We think that using multi-frequency as sending signal the error depending on a phase difference can be suppressed.

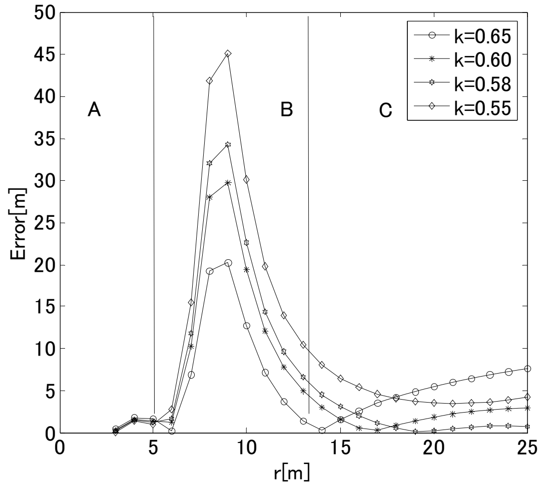

Fig.9. Error compensation of water-tank experiment

V. CONCLUSION

In this study we confirmed a new method that is using both of direct wave and reflected wave. This method is suited to the case that sensor is near to surface or bottom. If the power of sender is sufficiently large, they can fix the position in wide area. Although secondly and thirdly reflected wave had a big influence in water tank experiment, those waves can be separated in T-zone in case of sea area. We found when we use plural sensors more than 2 and take the average of them, can decrease this error. In addition, the difference of PL for each sensor can be used for phase difference detection. Consequently, using this method correct positioning is possible without time synchronization of the transmission and reception side.

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